β decay studies of ^{11}Be and ^{8}B with an implantation technique

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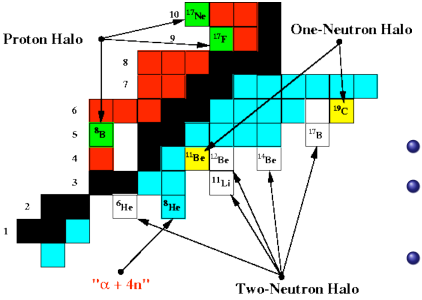
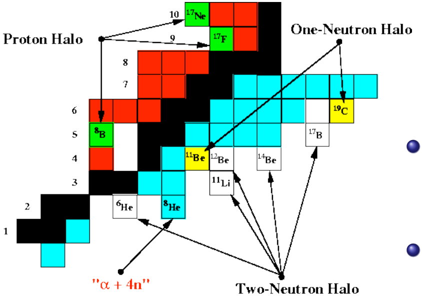
Outline

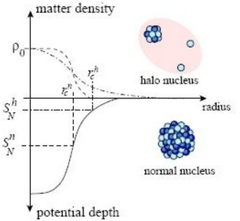
Light exotic nuclei - halo systems



- testing ground for nuclear models
- connection between shell model and cluster model
- connection between shell model and collective (Nilsson) model
- advent of radioactive beam facilities greatly improved on the knowledge of the structure of nuclei far from stability

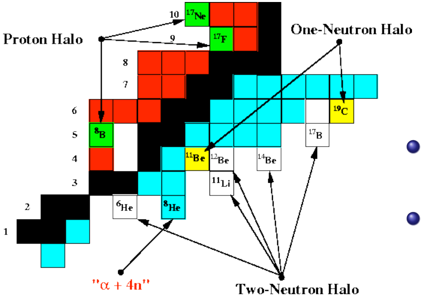
Light exotic nuclei - halo systems

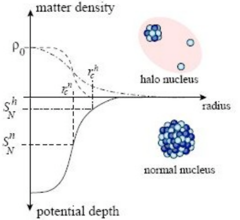




- nuclear halo=threshold effect
  very weak binding of the last one or two valence nucleons
- ....+ short range nuclear force
  large probability of tunneling into classically forbidden region
  compact core + valence nucleons
- lifetime ms-s

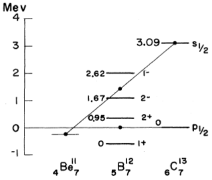
Light exotic nuclei - halo systems



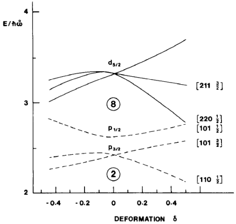


- reaction studies:
  level energies, spectroscopic factors, etc.
- well understood β-decay:
  - large Q-values,
    low break-up threshold of the daughters
    $\Rightarrow$ decay into unbound states
  - decay rate $\Rightarrow$ overlap

The one-neutron halo nucleus ^{11}Be



[I.Talmi and I.Unna, PRL4 (1960) 469]

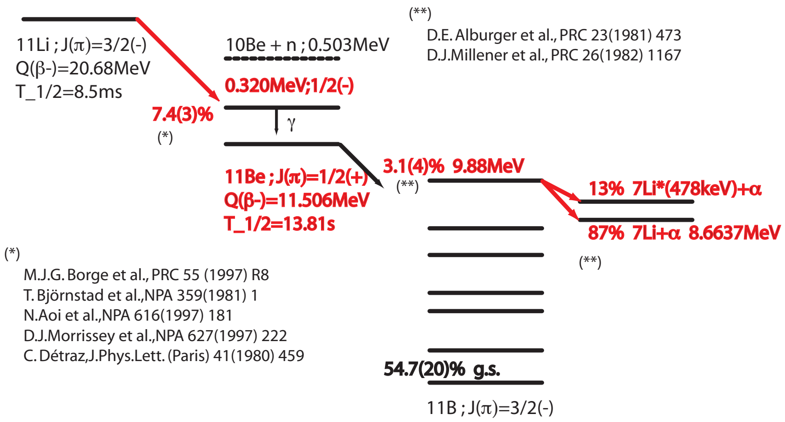


[Aa.Bohr and B.R.Mottelson, Nuclear Structure, vol II p.221]

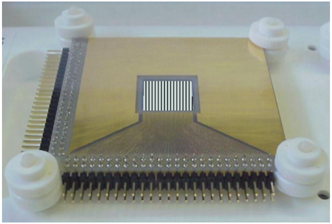
Non-normal parity ground-state $\frac{1}{2}^+$ where $\frac{1}{2}^-$ is expected from the classical shell model ordening of the single-particle orbitals

- extrapolation of $p_{1/2}$-$s_{1/2}$ difference in N=7 isotones
- similar to competition between $d_{5/2}$ and $s_{1/2}$ in N=9 isotones
- deformation of ^{11}Be
- surprisingly long half-life of ^{11}Li = 8.5ms
- <2% g.s. feeding in ^{11}Li β-decay

Charged particle emission in the β-decay of ^{11}Be



Implantation - decay correlation



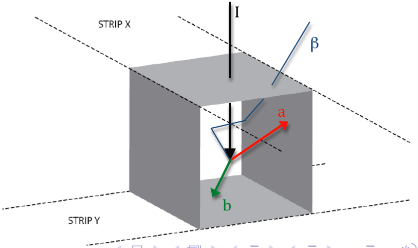
DSSSD : 16×16 mm^2, 78 μm thick

48+48 strips, 300 μm wide, 2304 pixels

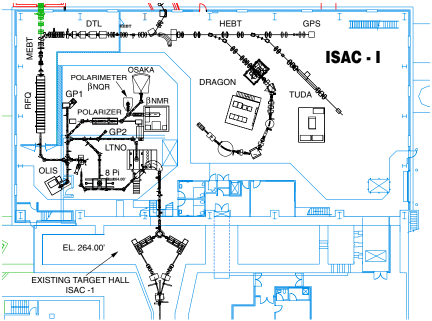
D. Smirnov et al., NIM A 547 (2005) 480

J. Büscher et al., NIM B 266 (2008) 4652

- high efficiency
- very precise normalisation
- full energy of ions is measured
- suppression of signals from β particles $\Rightarrow$ low detection threshold
- "history" of each decay

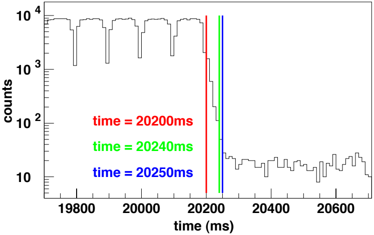


The ^{11}Li beam at ISAC



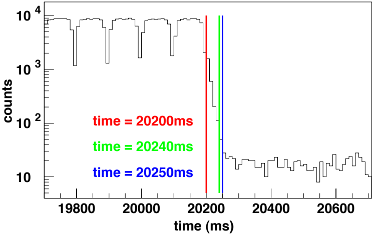
- proton beam (500 MeV, 35 μA) from cyclotron on Ta target
- separation and post-acceleration to the TUDA station
- used beams: ^{11}Li, ^{8}Li, ^{9}Li at 1.5 MeV/nucleon
- 1^{st} experiment with a post-accelerated radioactive ion beam at ISAC1 (2005)
- branching ratio for ^{9}Li+d and ^{8}Li+t channels

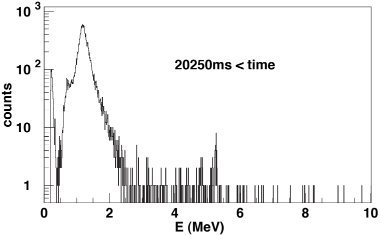
^{11}Li implantation - ^{11}Be decay



- ^{11}Li implantation ; $T_{1/2}$=8.5ms
  20s-20s beam on-off
  11×10^6 implantations

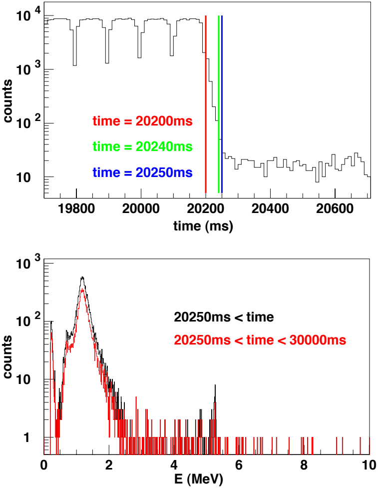
^{11}Li implantation - ^{11}Be decay





- ^{11}Li implantation ; $T_{1/2}$=8.5ms
  20s-20s beam on-off
  11×10^{6} implantations
- ^{11}Be decay ; $T_{1/2}$=13.81s

^{11}Li implantation - ^{11}Be decay



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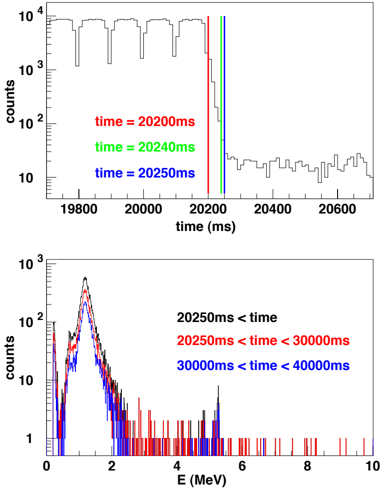
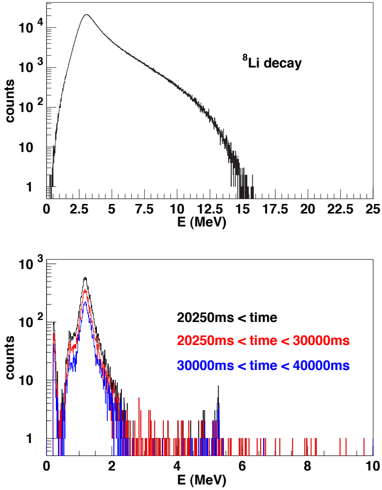


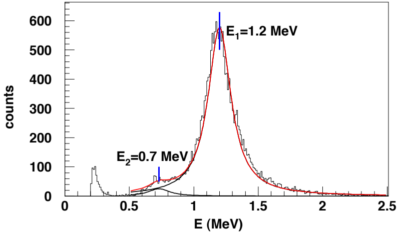
- ^{11}Li implantation ; $T_{1/2}$=8.5ms
  20s-20s beam on-off
  11×10^{6} implantations
- ^{11}Be decay ; $T_{1/2}$=13.81s
- **constant α background**
- ^{8}Li decays in range 2.5MeV-5MeV

^{11}Li implantation - ^{11}Be decay



- contribution in range 2.5MeV-5MeV fit with
  ^{8}Li$\rightarrow$2α (100%) decay spectrum
  taken in 2.5s-2.5s beam on-off cycle
- branching ratio for ^{8}Li+t channel:
  $(2.51\pm0.24)\times10^{-4}$
- good agreement with value from decay correlation procedure:
  $(2.15\pm0.17)\times10^{-4}$
  [R.Raabe et al., PRL101 (2008) 212501]
  ^{9}Li+d channel

Decay spectrum

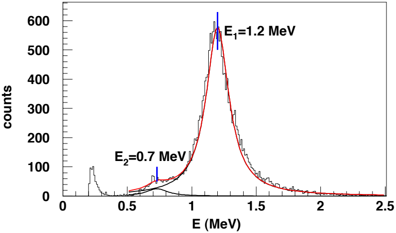


25000ms<time

- $^{11}B^*(9.88MeV) \rightarrow {}^{7}Li + \alpha$:
  peak at $E_1 = 1.2MeV$

  $^{11}B^*(9.88MeV) \rightarrow {}^{7}Li^*(478keV) + \alpha$:
  peak at $E_2 = 0.7MeV$

Decay spectrum



25000ms<time

- $^{11}B^*(9.88MeV) \rightarrow {}^7Li + \alpha$:
  peak at E_1=1.2MeV
  96% ↔ 87%
  $^{11}B^*(9.88MeV) \rightarrow {}^7Li^*(478keV) + \alpha$:
  peak at E_2=0.7MeV
  4% ↔ 13%
- large discrepancies
- theoretically subject to great uncertainties because of small spectroscopic factors for the breakup of the 9.88MeV $\frac{3}{2}^+$ state into $^7Li^{(*)} + \alpha$
  W.D.Teeters and D.Kurath, NPA275 (1977) 61
  S.Cohen and D.Kurath, NP73 (1965) 1

Decay spectrum

- total integral:
  0.423(3)% of ^{11}Li-decay
  $= \mathrm{BR}(^{11}\mathrm{Li}\rightarrow{}^{11}\mathrm{Be}(320\mathrm{keV}))\times$
  $\mathrm{BR}(^{11}\mathrm{Be}\rightarrow{}^{11}\mathrm{B}(9.88\mathrm{MeV}))$

Literature values

- $\mathrm{BR}(^{11}\mathrm{Li}\rightarrow{}^{11}\mathrm{Be}(320\mathrm{keV}))$:
  $(5.2\pm1.4)\%$, $(9.2\pm0.7)\%$,
  $(6.3\pm0.6)\%$, $(7.8\pm0.8)\%$,
  $(7.6\pm0.8)\%$
  weighted average: $(7.4\pm0.3)\%$
- $\mathrm{BR}(^{11}\mathrm{Be}\rightarrow{}^{11}\mathrm{B}(9.88\mathrm{MeV}))$:
  $(3.1\pm0.4)\%$

Decay spectrum

- total integral:
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  $= BR(^{11}Li \rightarrow ^{11}Be(320keV)) \times BR(^{11}Be \rightarrow ^{11}B(9.88MeV))$
- $BR(^{11}Be \rightarrow ^{11}B(9.88MeV)) =$ (5.7±0.5)%

Literature values

- $BR(^{11}Li \rightarrow ^{11}Be(320keV))$:
  (5.2±1.4)%, (9.2±0.7)%, (6.3±0.6)%, (7.8±0.8)%, (7.6±0.8)%
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- $BR(^{11}Be \rightarrow ^{11}B(9.88MeV))$:
  (3.1±0.4)%

Decay spectrum

- total integral:
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  $= \mathrm{BR}(^{11}\mathrm{Li} \rightarrow {}^{11}\mathrm{Be}(320\mathrm{keV})) \times \mathrm{BR}(^{11}\mathrm{Be} \rightarrow {}^{11}\mathrm{B}(9.88\mathrm{MeV}))$
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- $\mathrm{BR}(^{11}\mathrm{Be} \rightarrow {}^{11}\mathrm{B}(9.88\mathrm{MeV}))$:
  $(3.1 \pm 0.4)\%$

Can we obtain the two BR's from our experiment separately?

Sensitive to β-particles?

Trying to derive the BR for pure β-feeding in the ^{11}Be decay

- open strip multiplicity to allow β particles in the energy spectrum
- ^{9}Li decay spectrum was measured
  known pure β-feeding of 50%
- compare β particles emitted in the ^{11}Be decay
  with β particles emitted in the ^{9}Li decay

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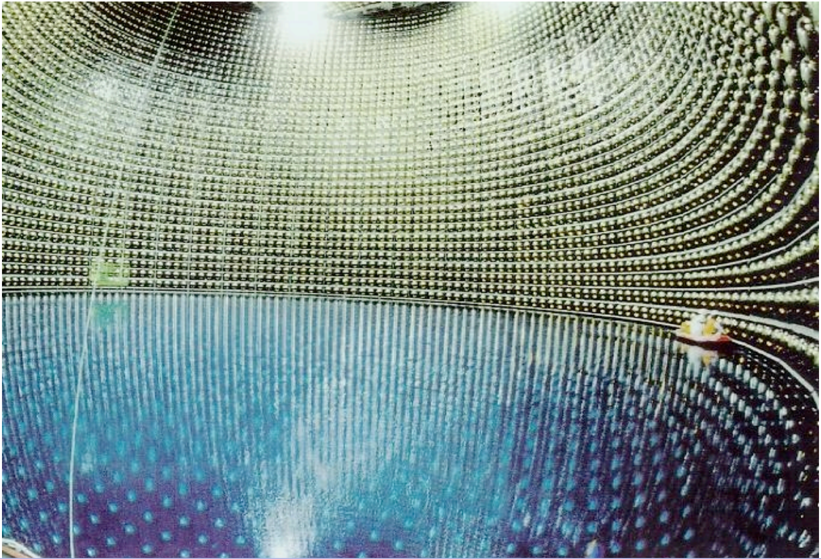
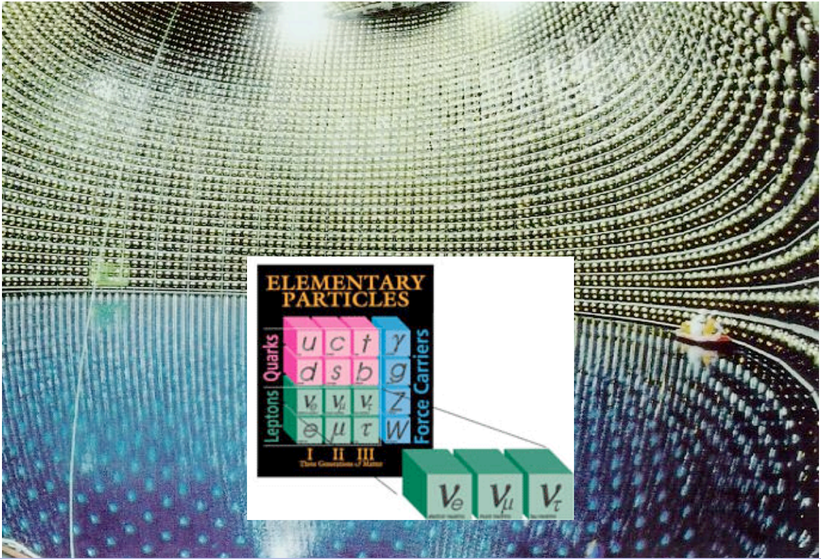
- open strip multiplicity to allow β particles in the energy spectrum
- ^{9}Li decay spectrum was measured
  known pure β-feeding of 50%
- compare β particles emitted in the ^{11}Be decay
  with β particles emitted in the ^{9}Li decay
- BR(^{11}Li$\rightarrow$^{11}Be(320keV))$\times$(1-BR(^{11}Be$\rightarrow$^{11}B(9.88MeV))): 8.93%

- BR(^{11}Li$\rightarrow$^{11}Be(320keV)):9.4%
  logft=5.55
  large value requires substantial amount of sd-mixing in the halo wave function of ^{11}Li: 50% s-wave
- BR(^{11}Be$\rightarrow$^{11}B(9.88MeV)):4.5%
  logft=4.07
  agrees with calculated 4.03 value for this allowed decay in a complete $1\hbar\omega$ representation sensitive to coupling of ^{10}Be core nucleus to sd-neutron and configuration of the final $\frac{3}{2}^{+}$ state in ^{11}B
  [W.D.Teeters and D.Kurath, NPA 275 (1977) 61]

neutrino's ...

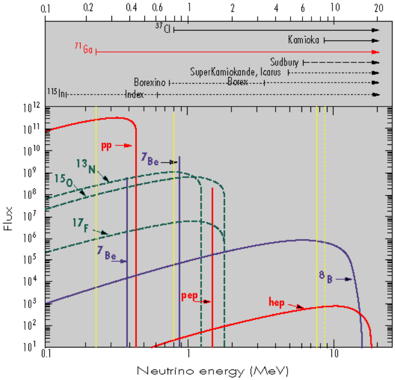


neutrino's . . .


ELEMENTARY PARTICLES
Quarks
Leptons
Force Carriers
u c t γ
d s b g
ν_e ν_μ ν_τ Z
e μ τ W
I II III
ν_e ν_μ ν_τ

Solar neutrinos and laboratory neutrinos

- Solar neutrino detectors
  Super-Kamiokande, Sudbury Neutrino Observatory (SNO), ICARUS
  are sensitive to neutrinos from
  $^{8}\text{B} \longrightarrow {}^{8}\text{Be} + e^{+} + \nu_e$



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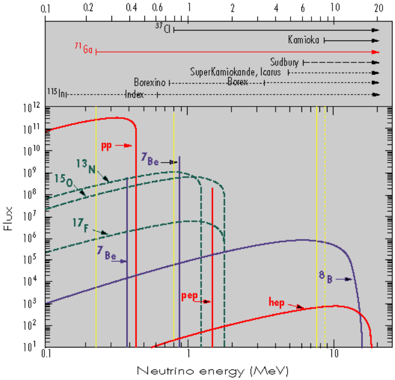
- The spectrum is depleted
  and distorted by neutrino oscillations;
  the distortion depends upon
  the oscillation parameters



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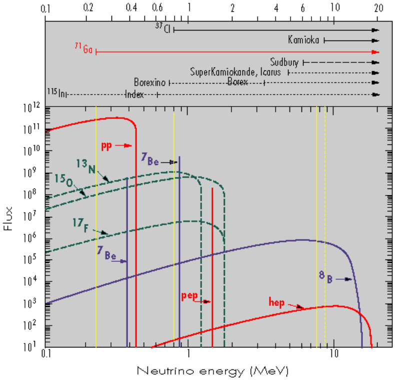
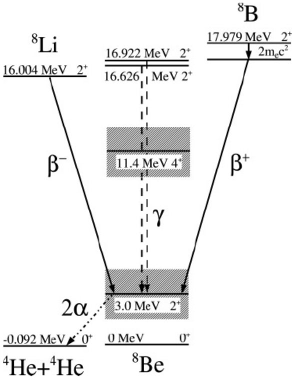
The unperturbed (laboratory)
neutrino spectrum
has to be known with high precision

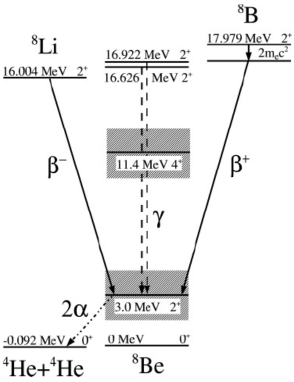


β-decay of ^{8}B



- Neutrino spectrum is derived from the shape of the 2^{+} continuum in ^{8}Be
- The resonance at 3.0 MeV dominates but higher states interfere

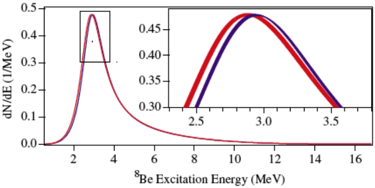
β-decay of ^{8}B



- Neutrino spectrum is derived from the shape of the 2^{+} continuum in ^{8}Be
- The resonance at 3.0 MeV dominates but higher states interfere

$\Rightarrow$ it has to be measured

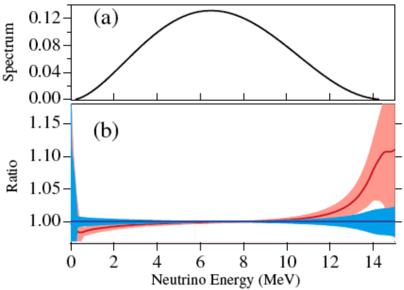
Present status



- Three measurements of the α spectrum since 2000:
  Ortiz et al.: coincident detection in a magnetic field
  Winter et al.: implantation in a Si detector
  Bhattacharya et al.: single α

- β-summing vs. recoil effects vs. energy losses

Present status



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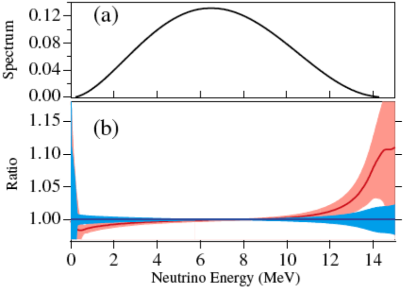

Can we improve?

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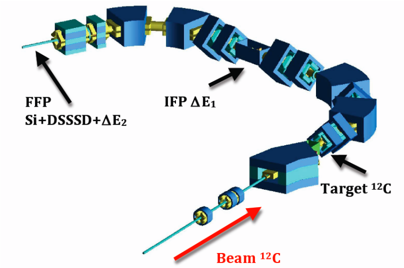
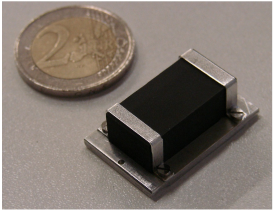
Measurement at Kernfysisch Versneller Instituut (KVI) - Groningen

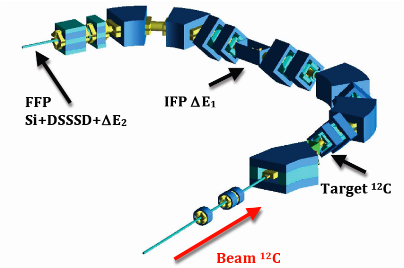


- Primary beam ^{12}C 5^{+} from AGOR Cyclotron, E=55MeV/u
- Fragmentation on ^{12}C target thickness=5000μm



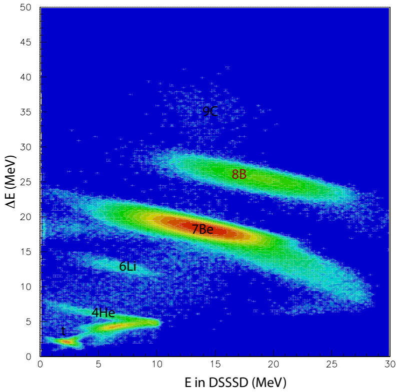
TRIμP=Trapped Radioactive Isotopes: μ-laboratories for Fundamental Physics

Measurement at Kernfysisch Versneller Instituut (KVI) - Groningen



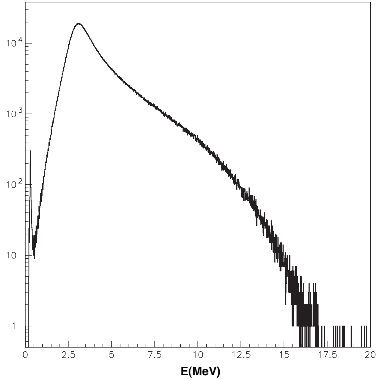
- ΔE_1 at IFP
- ΔE_2 at FFP in front of DSSSD
- coincidence Si detector (β) behind DSSSD
- Calibration with ^{148}Gd, standard triple α-source
- Calibration of DSSSD with implanting ^{20}Na $\rightarrow$ ^{16}O+α free from dead-layer effects
- Stable conditions! $\rightarrow$ cooling reducing the leakage current and improve resolution

Preliminary results and outlook



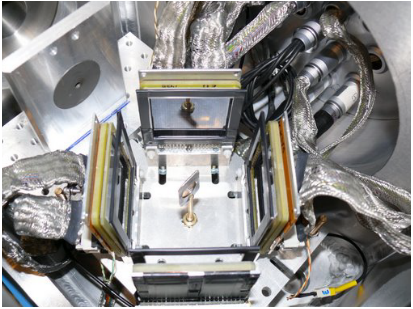
- identification profile : ΔE vs E(DSSSD)
- contaminants filtering

Preliminary results and outlook



- identification profile : ΔE vs E(DSSSD)
- contaminants filtering
- gate on energy and anticoincidence
  ΔE and DSSSD
  back detector and DSSSD
- 2α E spectrum
- $\approx 4.5 \times 10^6$ decays
- low energy threshold

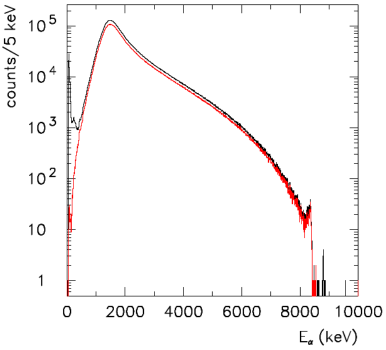
Preliminary results and outlook



Complementary experiment at Jyväskylä

- ^{6}Li(^{3}He,n)^{8}B
- Implantation on a C-foil
- Four surrounding DSSSD's

Preliminary results and outlook



[O. Kirsebom et al.]

Complementary experiment at Jyväskylä

- ^{6}Li(^{3}He,n)^{8}B
- Implantation on a C-foil
- Four surrounding DSSSD's
- 29.5×10^{6} α's in singles
  24.5×10^{6} α's in coincidence
- Analysis in progress
- Comparison important to account for systematic uncertainties
- Also compare with ^{8}Li decay information about 2^{+} continuum in ^{8}Be

Summary

Implantation technique

- Direct implantation of radioactive beams in a DSSSD

^{11}Be

- ^{7}Li$^{(*)}$+α feeding
- discrepancies with tabulated values
- measurement of branching ratio for ^{8}Li + t channel

^{8}B

- search for the unperturbed neutrino spectrum
- 2α energy spectrum

The collaboration

- IKS, Leuven, Belgium
  Beyhan Bastin, Jeroen Büscher, Mark Huyse, Oleg Ivanov, Ivan Mukha, Shelly Lesher, Dieter Pauwels, Jan Ponsaers, Riccardo Raabe, Maria Sawicka, Dmitry Smirnov, Irina Stefanescu, Emil Traykov, Jarno Van de Walle, Piet Van Duppen
- TRIUMF, Vancouver, Canada
  Andrei Andreyev, Lothar Buchmann, Pierre Capel, Rituparna Kanungo, Thomas Kirchner, Colin Morton, Jonathan Pearson, Götz Ruprecht, Pat Walden
- SFU, Burnaby, Canada
  Jennifer Jo Ressler, Chris Ruiz
- Colorado School of Mines, Golden, USA
  Caleb Mattoon, Fred Sarazin
- Dept. of Physics and Astronomy, University of Aarhus, Denmark
  Christian Diget, Hans Fynbo, Karsten Riisager, Solveig Hyldegaard, Oliver Kirsebom, Hans Hendrik Knudsen
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